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STATUS REPORT ON THE FRENCHMAN FLAT AMMONIA SPILL STUDY

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ABSTRACT

A series of four ammonia spills were made at Frenchman's Flat in Nevada as a part of a joint government-industry study. This paper outlines how the tests were conducted and the status of the data reduction.

1. INTRODUCTION

A series of four large-scale (15-60 m^3) pressurized NH_3 spill tests were conducted by the Lawrence Livermore National Laboratory (LLNL) for the U.S. Coast Guard, The Fertilizer Institute and Environment Canada as part of a joint government-industry study. The NH_3 tests, called the Desert Tortoise series were performed during August and September of 1983 on the Frenchman Flat area of the Department of Energy's (DOE) Nevada Test Site (NTS). The major purpose of the test series was to measure, for simulated accidental releases, the atmospheric dispersion of the spilled material under various meteorological conditions.

The ammonia tests were followed immediately by the Eagle series of spills of liquid nitrogen tetroxide (up to 3.5 m^3) for the U.S. Air Force. The two test series were conducted using nearly the same diagnostic instrument array and many of the same instruments. This resulted in considerable cost savings for the test sponsors. Setup for the two test series began on July 12, 1983 with ammonia tests occurring between August 24 and September 6. Change-over to the N_2O_4 configuration began on September 8 with N_2O_4 testing occurring between September 17 and November 30.

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The purpose of this paper is to describe how the ammonia spill tests were performed and to present a portion of the final results. Complete results will soon be published in the Desert Tortoise Series Data Report. A brief description of the experiments and diagnostics is included along with the presentation of some of the important results. Koopman et al (1984) presented some of the preliminary data, and compared the measured gas concentration vs. downwind distance with several dispersion model predictions.

2. DESCRIPTION OF THE EXPERIMENTS

The temporary spill facility used for the NH_3 tests is shown in Fig. 1. Two 10960 gal (41.5 m^3) capacity highway tanker trucks from California Ammonia Transport were specially modified to permit high discharge rates via a 4" port at the bottom of each tanker. These four-inch lines were connected to a six-inch diameter spill line having a remotely operated spill valve, flow meter, temperature and pressure transducers, and an orifice plate at the end. Although the ammonia at ambient temperature was self-pressurized to several hundred psia, additional gas from a high pressure gaseous nitrogen tube trailer was used to continuously force the NH_3 out of the tanker trucks at a constant rate, to purge the system, and to provide actuator gas for the remote-control valves. The end of the spill pipe was fastened rigidly to the ground 0.79 m above ground level, pointing horizontally downwind. The 3.72-inch diameter orifice plate was sized such that the NH_3 remained liquid until reaching the orifice plate, whereupon it flashed to a mixture of vapor and droplets.

On days with a favorable weather forecast, a typical spill test would be done as follows. The diagnostic system would be checked for satisfactory operation, and the spill area would be cleared of all personnel except for the arming team. Members of the arming team would open the manual valve on the N_2 tube trailer, set the pressure control valve to the desired drive gas pressure, open the manual valves on the tanker trucks and arm the control system. The team would then leave the area. All further spill operations would be conducted remotely. Control of the spill facility and data acquisition and recording was done by the Command and Control Data Recording System (CCDRS) at a site about 1 km upwind. The wind field measured at 11 locations encompassing the spill array was then monitored. When the wind speed and direction satisfied the experimental test and safety criteria, the tanker trucks were pressurized and the spill was initiated. Once the desired amount had been spilled, the spill was terminated. After the vapor cloud had cleared the downwind array, the pressure in the tanker trucks would be vented to rid the system of nitrogen and ammonia vapor and the disarming team would then re-enter the area, close the manual valves on the tanks and secure the facility.

Numerous measurements were made in the spill region including the temperature and pressure of the fluid just prior to its exit from the spill pipe. Three thermocouples were placed just at the surface of the soil at 3, 6, and 9 m downwind, and one heat-flux sensor was placed just below the soil surface at 3m downwind. Atmospheric boundary layer, wind field, vapor cloud temperature and concentration, and surface heat flux measurements were also made using an extensive diagnostic system developed by LLNL. There were two main arrays of diagnostic instruments: the meteorological array, and the dispersion array. The locations of the various stations making up these arrays, along with the positions of the camera stations, are shown in Fig. 2.

The meteorological array consisted of the eleven two-axis, cup-and-vane anemometers (all at a height of 2 m), plus a 20-m tall meteorological tower located 50 m upwind of the spill area. Wind speed and direction at each station were vector-averaged for 10 sec, and the results, plus the standard deviation of direction for the same period, were transmitted back to the CCDRS trailer and displayed in real time. This display was the primary information used to determine the optimum time for a spill. The meteorological tower was outfitted with four temperature gauges and three Gill bivane anemometers to measure temperature and wind speed profiles. This station also measured the ambient ground heat flux. Humidity data and local barometric pressure were obtained from the Weather Service Nuclear Support Office.

The dispersion array was made up of four rows of stations. The purpose of this array of sensors was to measure the downwind dispersion by recording the concentration, temperature, and dimensions of the gas cloud during each spill test. The 100 m row consisted of seven stations with gas and temperature sensors at 1, 3, and 6 m heights. The centerline station had a 10 m tall tower outfitted with three bivane anemometers, plus other sensors listed in Table I. The remaining six stations had 6 m tall masts and each was outfitted with instruments as indicated in Table I, with the stations located at 15.24 m intervals to either side of the centerline station (three to each side). Ammonia concentrations were measured using Mine Safety Appliances (MSA) nondispersive IR gas sensors. Gas plus aerosol was passed through a heating apparatus to vaporize the aerosol and allow the total amount of NH_3 present to be determined.

TABLE I. SPILL ARRAY INSTRUMENTATION USED ON THE NH_3 TESTS.

			Distance from spill location (km)				
Measurement	Instrument	Number	0.0	0.1	0.8	1.4/2.8	5.5
Gas concentration	MSA NDIR	20		x			
	LLNL IR	31		x	x		
	IST	24	x		x	x	x
	Dosimeter	8				x	x
Temperature	Thermocouple	36	x	x	x		
Aerosol density	Beta gauge	5		x			
	Nephelometer	2		x			
	Particle counter	1		x			
Heat flux	Hy-Cal	5	x	x			

The second row of the dispersion array consisted of five 10-m-high towers located 800 m downwind of the spill area (see Fig. 2). Each tower had gas sensors and thermocouples located at heights of 1, 3.5, and 8.5 m above the ground. A typical data acquisition station of this type is shown in Fig. 3. The towers were separated by a distance of 100 m. In addition, there were up to eight portable ground-level stations in arcs at distances of 1450 or 2800 m, and on occasion, at 5500 m downwind. See Tables I and II for details on number of instruments and placement. Additional diagnostic instruments were also used, including cameras, and are listed in Table II. LLNL IR gas sensors (Bingham et al, 1983) were fielded in the 800 m arc to provide a greater dynamic range for gas concentration measurements and to serve as a check on the IST sensor calibrations. These four-band IR absorption sensors were originally designed for detection of liquefied natural gas (LNG) vapors and were not optimal for detecting NH_2; however, they were usable for ammonia concentrations above 1%.

TABLE II. ADDITIONAL INSTRUMENTATION USED ON AMMONIA TEST SERIES.

Spill Facility Measurements	Weather Measurements
• Flow rate	• 2-axis anemometer array of 11 stations
• Tank pressure	• 3-level, 3-axis anemometers at 2 stations
• Exit pressure	• Humidity
• Exit temperature	• Barometric pressure
• ground temperature (3)	• Temperature at 4 heights
• Pool Temperature (3)	
• Heat flux	

Photo Documentation

- Movie cameras (4)
- Still cameras (4)
- Videotape (1)

The 100 m and 800 m rows were also employed as a mass flux array to serve as a means of determining source strength and to provide checks on the accuracy of gas sensor results. This was accomplished by measuring the gas/aerosol concentration, vapor cloud temperature and velocity as it passed through the row. The product of the mass density and velocity integrated over the vapor cloud cross-section yields the total mass flux passing through the row at any instant. If the entire cloud is within the row, this mass flux should be equivalent to the source strength of the spilled material. Also, in the absence of pooling, the integrated mass should equal the total amount of ammonia spilled.

Control of the spill facility and acquisition and storage of the sensor array data was performed by the CCDRS at the upwind control trailer. This system utilizes two-way UHF radio telemetry for command and data transmission and is designed to acquire data from microprocessor-controlled sensor stations distributed over an area with a diameter of up to 10 miles (Johnson, 1984 and

Baker, 1982). The individual remote data acquisition stations are battery-powered, portable, gas-tight, and ruggedized. Batteries are recharged by solar cells. This network of 25 stations acquired data from 306 channels at a rate of one sample per second for the gas and control stations and once per 10 seconds for the wind-field stations.

After each test, raw data are converted on an LSI-11/23 minicomputer to calibrated data sets. These reduced data, together with sensor calibration files and data acquisition control files and dayfiles, are written to ASCII magnetic tape and transferred to the LLNL Computation Center for archival preservation. Data are stored on an off-line mass storage system and are readily available for analysis.

3. RESULTS

Four tests were conducted between August 24 and September 6, 1983. Frenchman Flat, site of early nuclear weapons tests in the atmosphere, is an extremely flat (normally) dry lake bed approximately 4-6 km long and 3 km wide. On the average, the surface layer at the center is less than 0.3 m below that at the edges. This almost level terrain together with regular wind flow patterns makes Frenchman Flat an excellent site for atmospheric gas dispersion experiments. In fact, the DOE's permanent spill test facility currently is being constructed less than 0.5 km away from the location of these tests. Although normally a dry desert, unusually heavy rain in early and mid August associated with El Nino weather patterns formed a lake at the site. During the calm of the nights before the first and second tests, several inches of water covered the region of the spill point and the array row at 100 m downwind, with 6-8 inches of water at the position of the 800 m row. In the morning, the winds started up. By test time water in the lake had been blown downwind leaving the close-in regions largely free of surface water, out to perhaps 400 m. However, the clay-like surface of the playa was saturated with water and numerous small pools of water a few mm deep were present. The lake bed was almost completely dry by the third test, and had completely dried up by the last test. Thus, the atmospheric boundary layer experienced was considerably different from the usual dry desert circumstances, and a greater than anticipated range of test circumstances was sampled. Figures 4 and 5 show scenes from the Desert Tortoise 4 test.

Finalized test summary data, listing spill conditions and meteorological conditions averaged for the duration of each spill, are given in Table III for the Desert Tortoise test series. Estimates of atmospheric stability class came from vertical temperature gradients and horizontal wind variability σ_θ. The array centerline was at 225°.

The remainder of this status report will concentrate on results from Desert Tortoise 4, the largest test with the most stable atmosphere of the series. The ammonia was released 0.79 m above the ground as a strong horizontal jet, pointing towards the center of the array. The extremely turbulent jet expanded rapidly due to the flashing of liquid into vapor and aerosol. An isentropic expansion from 24°C would result in 17% vapor and 83% liquid droplets. Portions of the released mass directly impacted the ground and a noticeable pool persisted for minutes after the end of this test. Most of the material, however, was carried downwind through the array rows as a heavier-than-air cloud. Effects of the strong jet persisted considerably past the 100 m row before the cloud was slowed to the ambient wind speed. Values of spill parameters for Desert Tortoise are given in Table IV. These values are averages over the time period of 100-300 seconds after the start of the spill, a region of relatively constant spill rate with liquid being expelled from both tankers.

TABLE III. TEST SUMMARY FOR DESERT TORTOISE SERIES NH_3 SPILLS.

Test	Date	Size (m^3*)	Rate (m^3/min)	Wind speed (m/s)	Wind direction	Stability class
1	8/24	14.9	7.0	7.4	224°	D
2	8/29	43.8	10.3	5.7	226°	D
3	9/1	32.4	11.7	7.4	219°	D
4	9/6	60.3	9.5	4.5	229°	E

TABLE IV. SPILL PARAMETERS FOR DESERT TORTOISE 4 (100-300s)

Spill rate	8.5 m^3/min
Tank pressure	203 psia
Soil temperature	30.8°C
Exit temperature	24°C
Exit pressure	171 psia
Pool temperature (3 m downwind)	-52°C
Pool temperature (6 m downwind)	-58°C
Pool temperature (9 m downwind)	-63°C
Ground heat flux	2.2 kw/m^2
Ambient temperature	32.8°C
Barometric pressure	903.09 mb
Relative humidity	21%
Dew point temperature	7.8%
U Star	0.286 m/s
T Star	0.410°C
Richardson Number at 2 m height	0.044
Monin-Obukhov length	45.2 m

Figure 4, taken upwind and slightly to the side of the spill point, shows the cloud just passing through the first row of sensors at 100 m downwind. The heavier-than-air cloud is approximately 70 m wide, and generally less than 6 m high. Cloud width was greater on this test than on the others, demonstrating the effects of greater atmospheric stability.

Figure 5 shows a side view of the cloud from the release point to a point approximately 300 m downwind. The ammonia and fog aerosol is clearly visible, and persisted to beyond 400 m. Heavy gas and strong jet effects dominate the dispersion.

Reduction of the gas concentration data from the 800 m row has been completed, and we will concentrate on these data. A vertical contour plot of the cloud as it passed the 800 m row is shown in Fig. 6. The maximum gas concentration seen at 800 m was about 2%. The cloud still was on the order of 6 m high, but had increased in width to about 400 m. The gas sensors at heights of 8.5 m showed very little, if any, gas and the cloud was generally contained within the array. A calculation of the mass flux through the 800 m row (assuming a constant wind speed of 4.5 m/s) was performed with the results shown in Fig. 7. This should be compared to the test average spill rate of 9.5 m^3/min or 108 kg/s. The mass flux was integrated yielding a cumulative mass of 21000 kg, approximately half of the amount spilled 41000 kg.

Correcting for miscentering of the cloud on the row (assuming a symmetric cloud shape) and for estimates of the effects of an increased cloud velocity at 800 m due to the strong jetting at the source, accounts for some 40% of the mass discrepancy. Cross checks of the IST and LLL-IR sensor results show pretty good agreement and suggest the gas concentration results are accurate to within 20%. Therefore, some few tens of percent of the mass spilled is unaccounted for at the 800 m arc. Some of this was due to liquid pooling at the source. Unlike the first two tests which were conducted on water-saturated surfaces, Desert Tortoise 4 definitely exhibited a pool on the ground after the test. It slowly boiled off and persisted for almost ten minutes. Small puffs of boiled-off gas were seen off and on in the 100 m row to at least 1100 seconds after the start of the spill. Little of this gas was seen at 800 m. A portion of the spill material therefore was subjected to nonadiabatic heating, presumably becoming buoyant. Additional losses may be due to aerosol effects, rainout of droplets and absorption into the ground, or persistance as droplets out to the 800 m arc where only the vapor content of the cloud was detected.

Table V presents preliminary results for Desert Tortoise 4 of the maximum gas concentrations and minimum temperatures detected at the various rows. Figure 8 shows a plot of the maximum gas concentration seen as a function of downwind distance, along with predictions provided by a modified transient Gaussian plume model (Koopman, et al, 1984) and the FEM3 code with a simple aerosol model (Chan, 1983 and Kansa et al, 1983). These model results were computed specifically for the test circumstances of Desert Tortoise 4.

TABLE V. PRELIMINARY RESULTS FOR DESERT TORTOISE 4.
MAXIMUM GAS CONCENTRATION AND MINIMUM TEMPERATURE VERSUS DOWNWIND DISTANCE

Gas Concentration and Temperature

	0 m	100 m	800 m	2800 m
Concentration	---	6.5%	2.0%	0.53%
Temperature	(32.8°C)	-7°C	+23°C	---

4. SUMMARY AND CONCLUSIONS

Four pressurized ammonia spill tests were conducted in summer 1983. Dense gas and aerosol effects were observed to persist well beyond the immediate region of the spill. The strong jetting action at the source also affected the cloud motion out to several hundred meters or more. Results from the last test indicated gas concentrations at 2.8 km almost an order of magnitude larger than those predicted by simple transient Gaussian plume models. The considerably more elaborate FEM3 code with its simple aerosol model and procedure for modeling the source jet somewhat overestimates the gas concentration versus distance, but the slope agrees with the experimental data. Since the slope at even greater distances is expected to merge eventually to that of the Gaussian models, those models will underpredict ammonia concentrations by a large factor, and they are clearly inadequate. Calculated results by the very large FEM3 code are in much better agreement with the experimental data, but FEM3 cannot economically be employed to model ammonia gas concentrations down to the several hundred ppm level. Therefore, improved simple models are required for predicting the consequences of accidental releases of ammonia.

In conclusion, the Desert Tortoise experimental results should be of substantial interest to those concerned with industrial safety and plant siting. Extensive data of high quality were obtained.

5. STATUS

All of the Desert Tortoise test data are being compiled into a data report which should be completed in the next few months. Interested parties who wish to be included in the distribution are invited to contact the author.

5. REFERENCES

Baker, J., The LLL Data Acquisition System for the Liquefied Gaseous Fuels Program, Lawrence Livermore National Laboratory, Livermore, CA, UCID-18576, March 1980.

Bingham, G.E., R.D. Kiefer, C.H. Gillespie, T.G. McRae, H.C. Goldwire, Jr., and R.P. Koopman, A Portable, Fast-Response Multiwavelength Infrared Sensor for Methane and Ethane in the Presence of Heavy Fog, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-84850, November 1980.

Chan, S.T., FEM3--A Finite Element Model for the Simulation of Heavy Gas Dispersion and Incompressible Flow: User's Manual, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53397, February 1983.

Johnson, G.W., The LGF Data Acquisition System 1983 Update, Lawrence Livermore National Laboratory, Livermore, CA, UCID-20138, August 1984.

Kansa, E.J., D.L. Ermak, S.T. Chan, and H.C. Rodean, Atmospheric Dispersion of Ammonia: An Ammonia Fog Model, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-88649, January 1983; Proceedings of the Multiphase Synfuels Heat Transfer 21st ASME/AIChE National Heat Transfer Conference, Seattle, WA, July 24-28, 1983.

Koopman, R.P., T.G. McRae, H.C. Goldwire, Jr., D.L. Ermak, and E.J. Kansa, Results of Recent Large Scale NH^3 and N_2O_4 Dispersion Experiments, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-91830, November 1984 presented at the Third Symposium on Heavy Gases and Risk Assessment, Wissenschaftszentrum Bonn, West Germany, November 12-13, 1984.

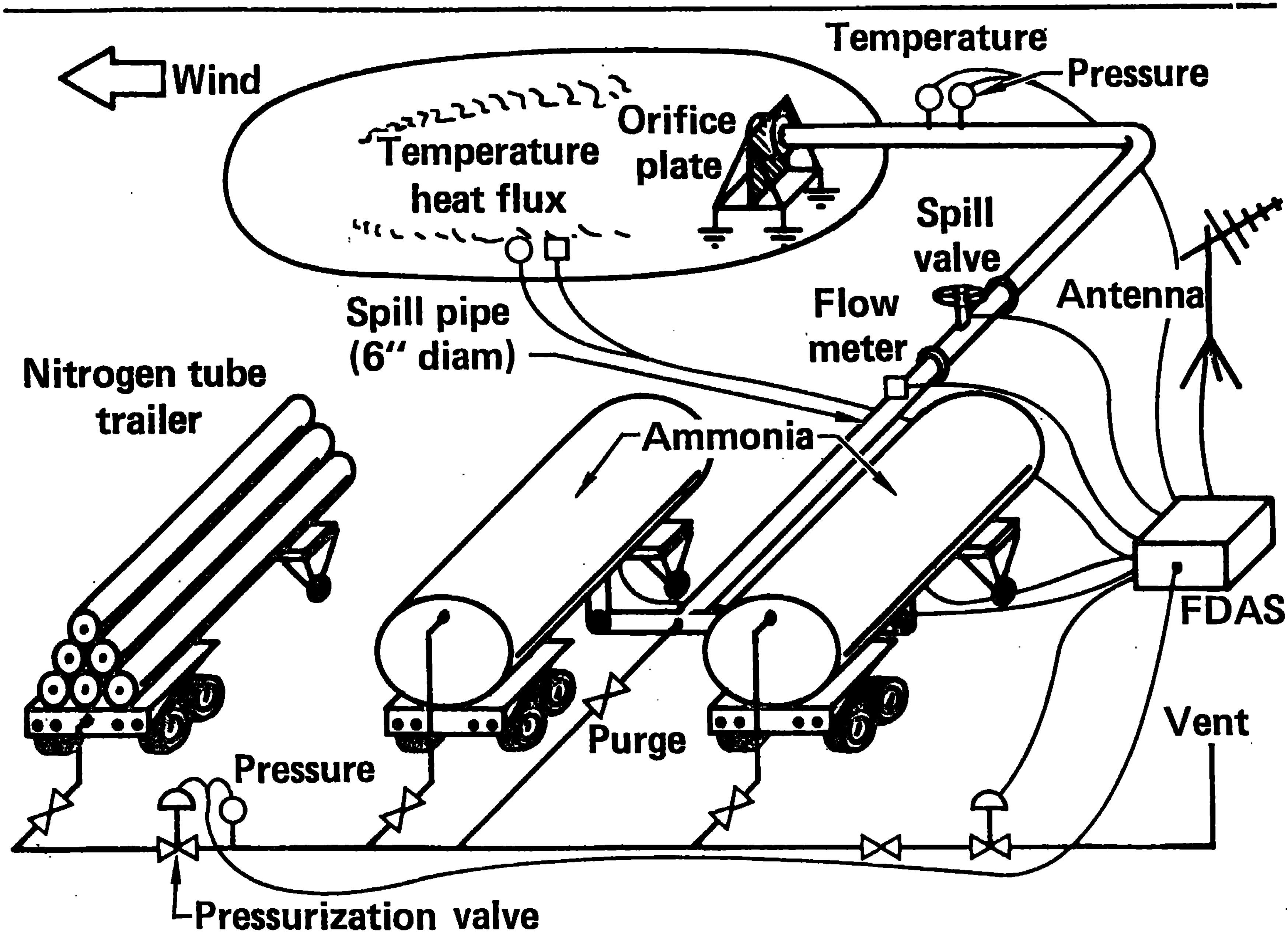

Fig. 1. Temporary ammonia spill facility used for the Desert Tortoise series of experiments at the Nevada Test Site in 1983.

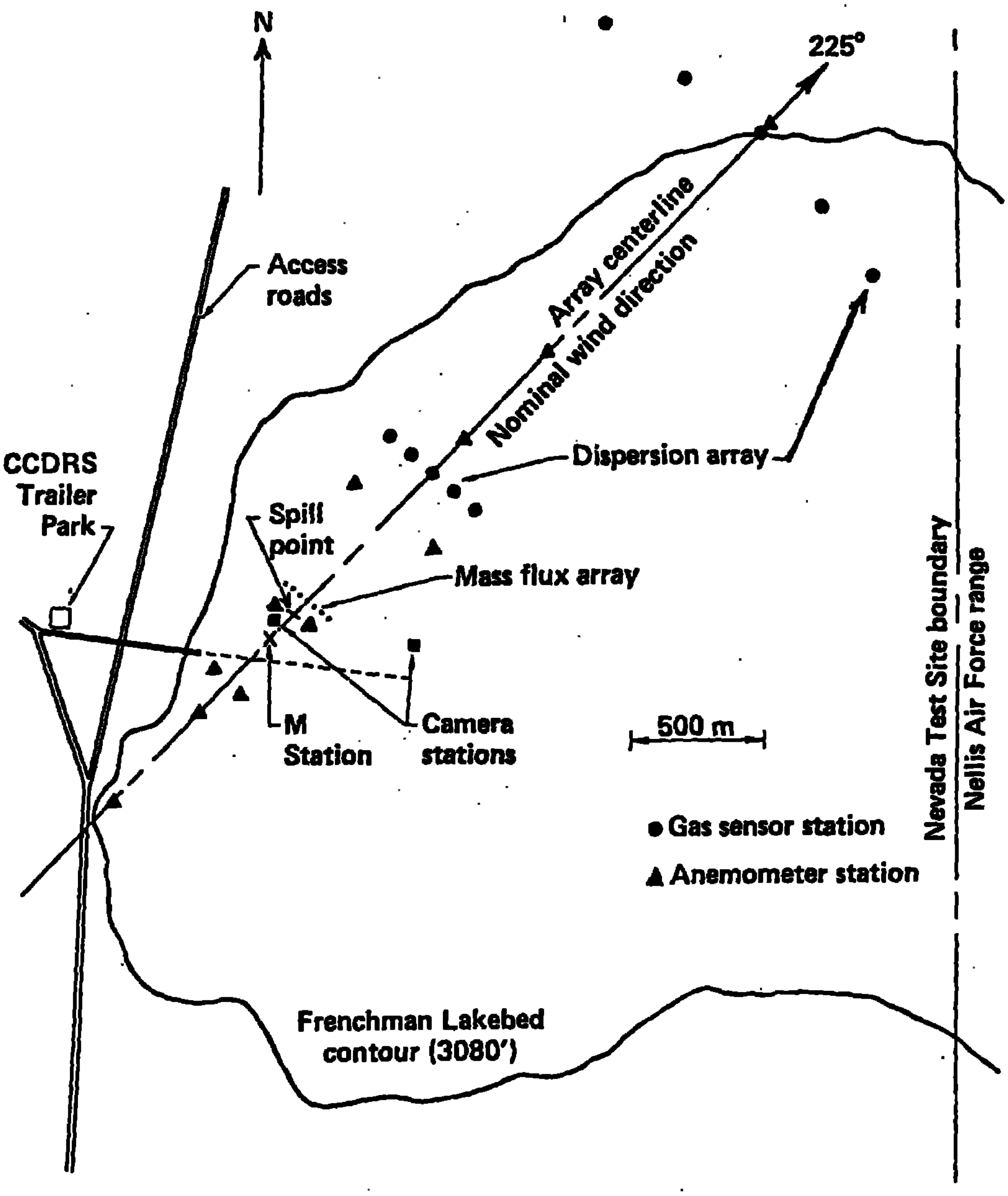

Fig. 2. Diagnostic instrument array for Desert Tortoise and Eagle series experiments.

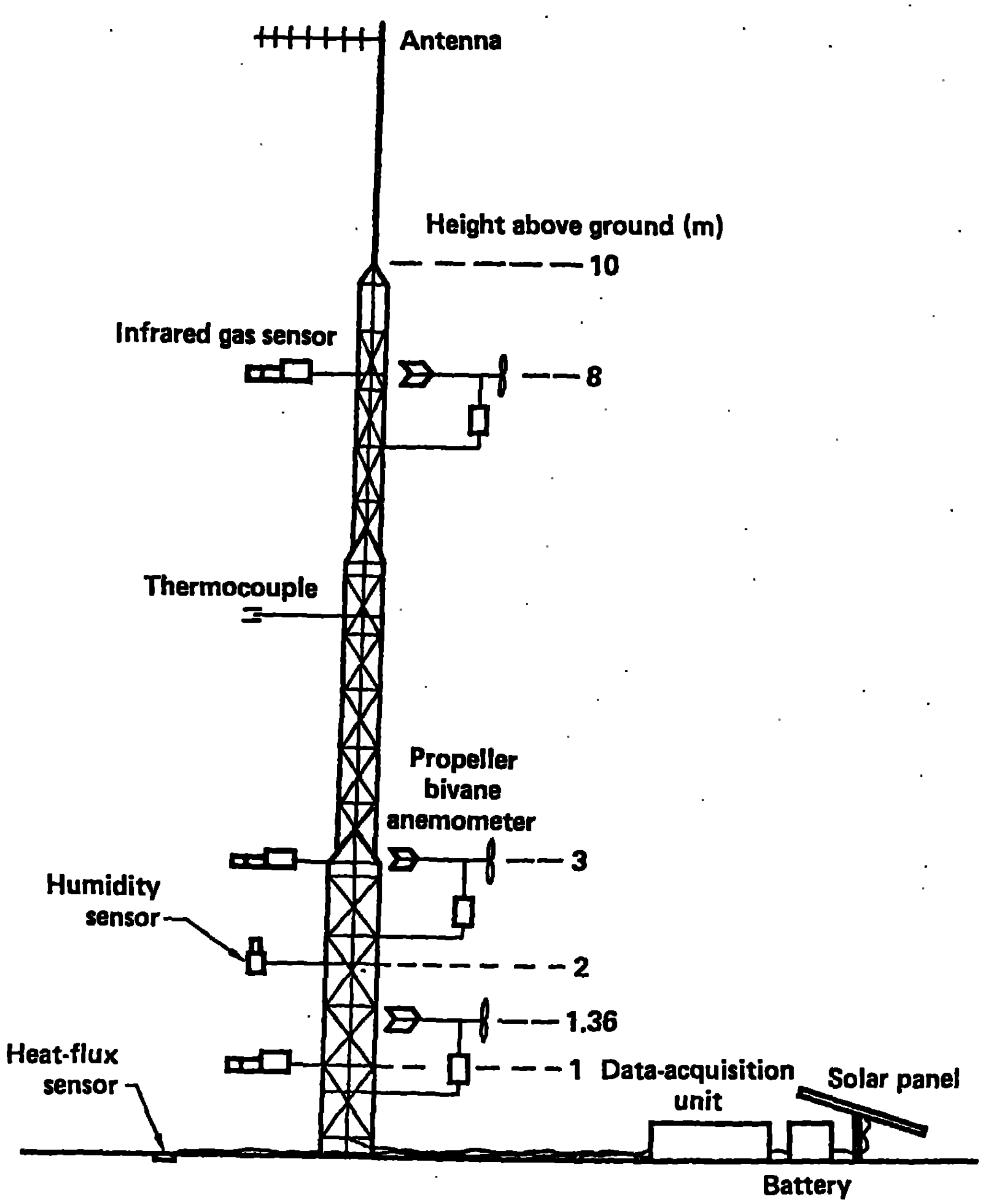

Fig. 3. A typical gas sensor station showing many of the instruments used for measurement of the dispersing gas cloud.

Fig. 4. Desert Tortoise 4 spill seen from upwind camera.

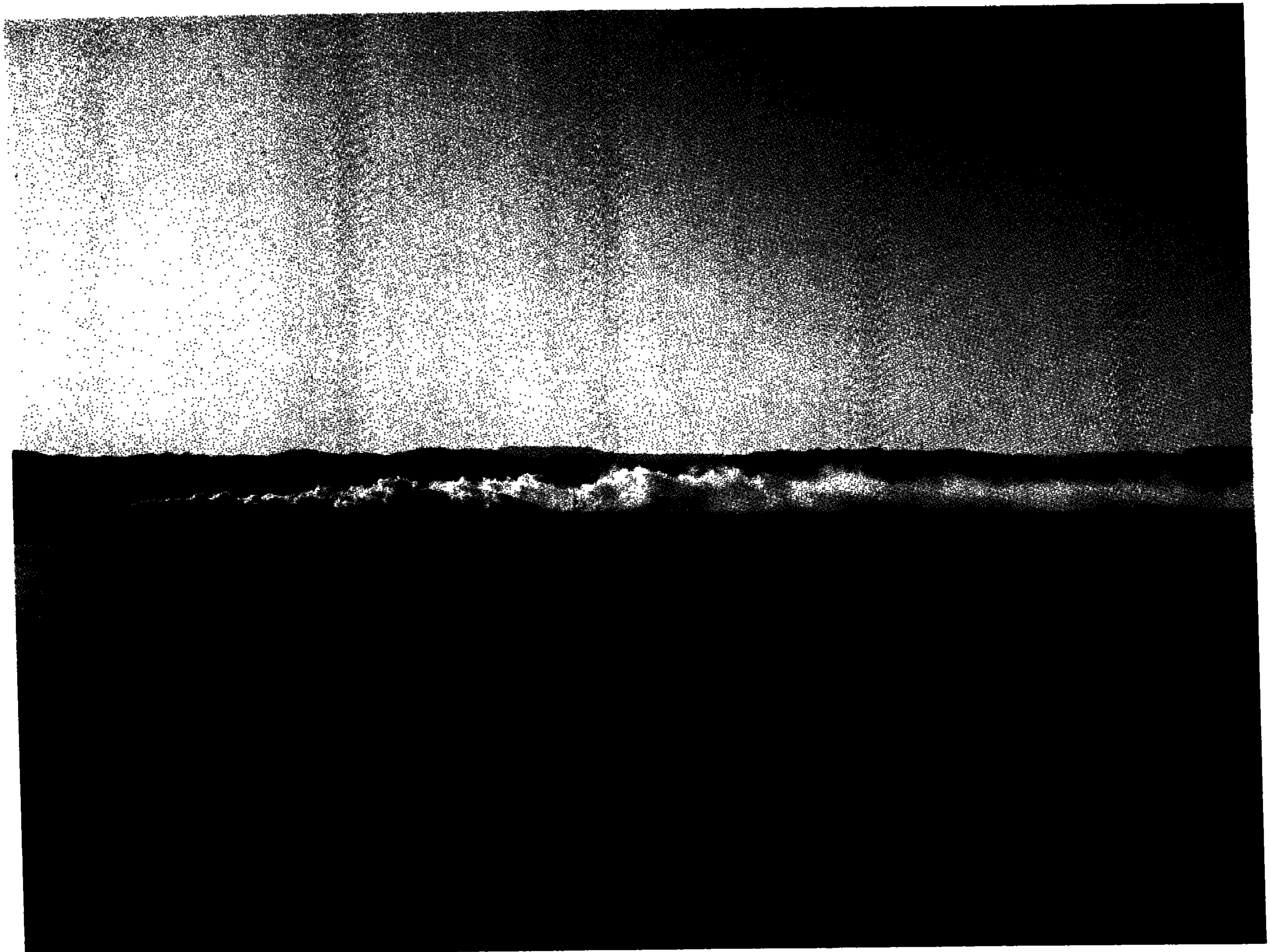

Fig. 5. Desert Tortoise 4 spill seen from side camera.

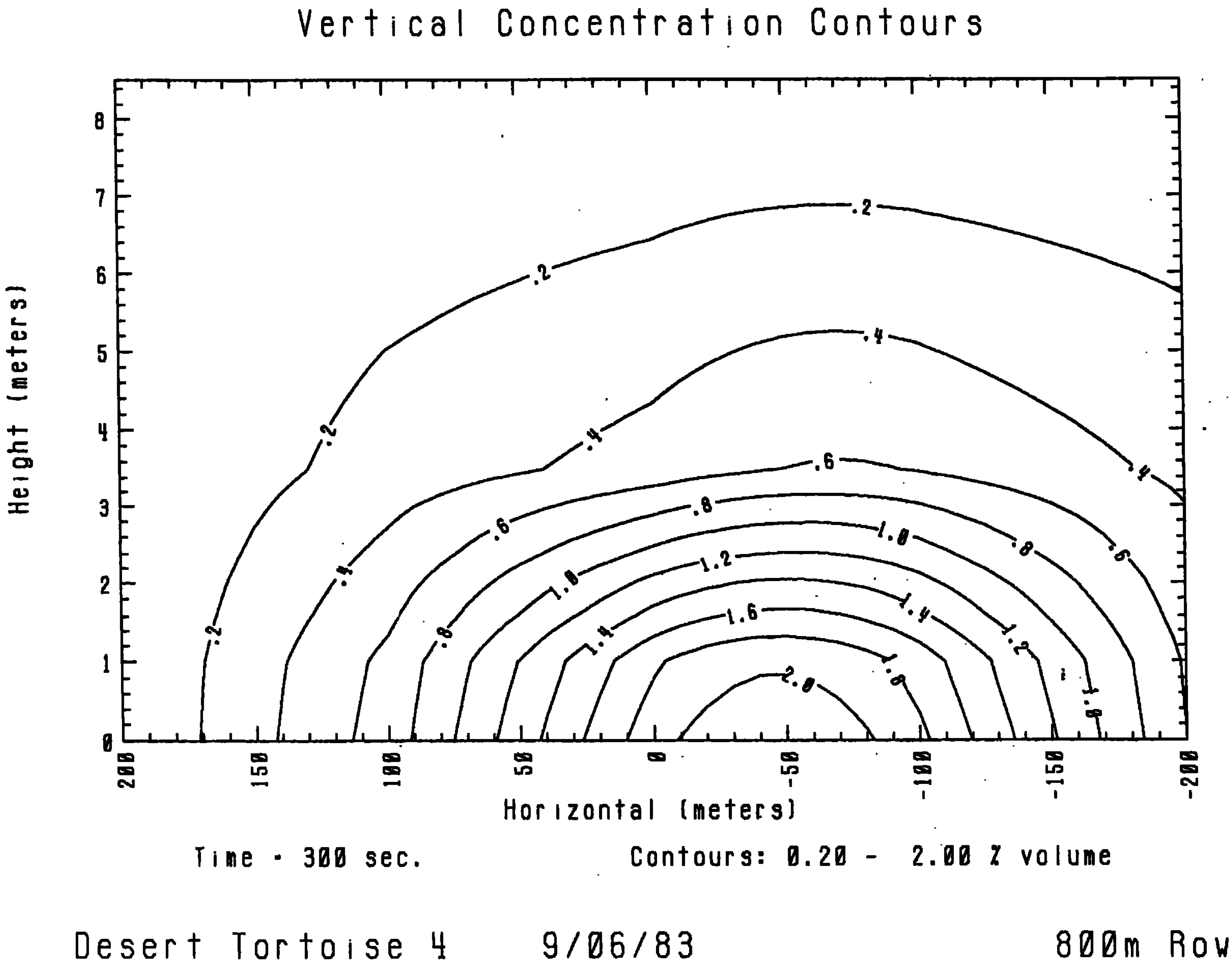

Fig. 6. Gas concentration in the vertical plane at the 800 m row.

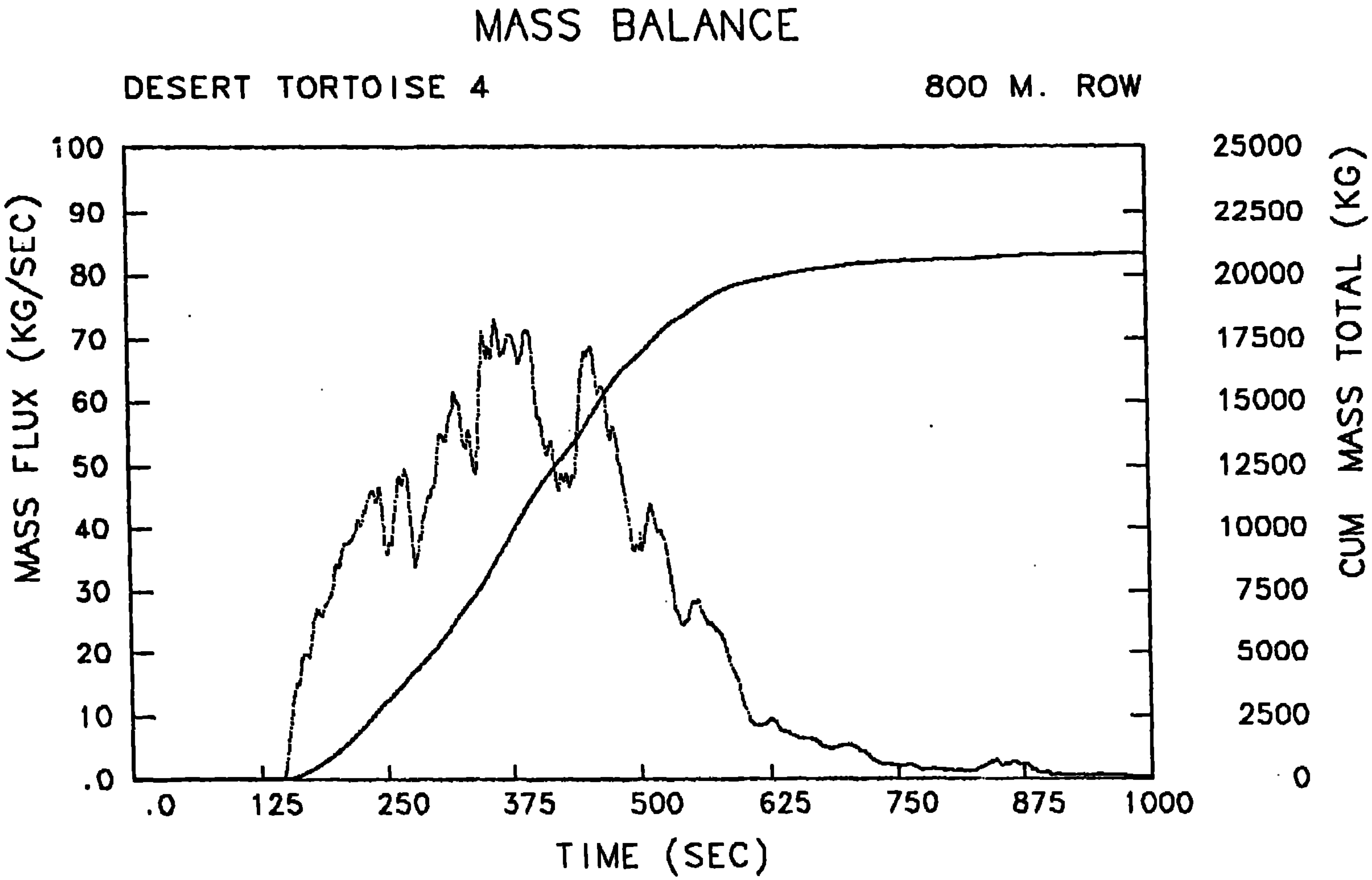

Fig. 7. Mass flux passing from the row at 800 m vs time and the cumulative total.

MODEL DATA COMPARISON FOR DESERT TORTOISE 4
60 m^3 AMMONIA SPILL